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In re Application of: :
WERNER SCHROEDER   :   Examiner:
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For: METHOD FOR DETERMINATION OF A: Art Unit:
      ZERO ERROR IN A CORIOLIS GYRO:

Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450

TRANSMITTAL OF SUBSTITUTE SPECIFICATION

Dear Sir:

Transmitted herewith is a (1) Substitute Specification and (2) marked-up version of the Substitute Specification.

The Substitute Specification was prepared and is filed for the purpose of correcting the text of the English language translation of International patent application PCT/EP2004/003248 that is submitted herewith. The translation, a literal translation of the International application that was prepared in the German language, contains numerous grammatical and syntactical errors that would unnecessarily complicate the examination of this application.

No new matter is added by the Substitute Specification.

The marked-up version indicates changes from the literal English language translation of PCT/EP2004/003248 by strikeout (deletions from literal English translation) and underline (additions to literal English translation).

Respectfully submitted,

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Title: METHOD FOR DETERMINATION OF A ZERO ERROR IN A
         CORIOLIS GYRO

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BACKGROUND

5   <u>Field of the Invention</u>

The present invention relates to Coriolis gyros.
More particularly, this invention pertains to a method for
determination of a zero error in a Coriolis gyro.

<u>Description of the Prior Art</u>

10   Coriolis gyros (also referred to as "vibration
gyros") are in increasing use for navigation. They
possess a mass system that is caused to oscillate with the
oscillation generally being the superposition of a large
number of individual oscillations.

15   The individual oscillations of the mass system
are initially independent of one another and can be
referred to abstractly as "resonators". At least two
resonators are required for operation of a vibration gyro:
one (the first resonator) is artificially stimulated to
20 oscillate, and this is referred to below as the
"stimulating oscillation". The other (the second

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resonator) is stimulated to oscillate only when the vibration gyro is moved/rotated. This is because Coriolis forces occur in this case that couple the first resonator to the second resonator, absorb energy from the

5   stimulating oscillation for the first resonator, and transfer it to the read oscillation of the second resonator. The oscillation of the second resonator is referred to below as the "read oscillation".

In order to determine movements (in particular

10 rotations) of the Coriolis gyro, the read oscillation is tapped off and a corresponding read signal (e.g. the read oscillation tapped-off signal) is investigated to determine whether any changes have occurred in the amplitude of the read oscillation, as they represent a

15 measure of the rotation of the Coriolis gyro.

Coriolis gyros may be implemented as both open-loop and closed-loop systems. In a closed-loop system, the amplitude of the read oscillation is continuously reset to a fixed value (preferably zero) by control

20 loops.

An example of a closed-loop version of a

Coriolis gyro will be described below in conjunction

Figure 2, a schematic diagram of a Coriolis gyro in

accordance with the prior art. The gyro 1 includes a mass

5   system 2 that can be caused to oscillate and is also

referred to below as a "resonator". (A distinction exists

between this expression and the abstract "resonators" term

previously employed for individual oscillations of the

"real" resonator. As mentioned, the resonator 2 may be

10   considered as a system composed of two "resonators" (a

first resonator 3 and a second resonator 4). Each of the

first and the second resonators 3, 4 is coupled to a force

sensor (not shown) and to a tapping system (not shown).

The noise produced by the force sensor and the tapping

15   systems is indicated schematically by Noise1 (reference

symbol 5) and Noise2 (reference symbol 6).

The Coriolis gyro 1 includes four control loops.

A first control loop controls the stimulating oscillation

(that is to say the frequency of the first resonator 3) at

20   a fixed frequency (resonant frequency). It comprises a

first demodulator 7, a first low-pass filter 8, a

frequency regulator 9, a VCO (voltage controlled

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oscillator) 10 and a first modulator 11.

A second control loop controls the stimulating oscillation at constant amplitude. It comprises a second demodulator 12, a second low-pass filter 13 and an

5   amplitude regulator 14.

Third and fourth control loops are employed to reset the forces that stimulate the read oscillation. The third control loop includes a third demodulator 15, a third low-pass filter 16, a quadrature regulator 17 and a

10   third modulator 22 while the fourth control loop comprises a fourth demodulator 19, a fourth low-pass filter 20, a rotation rate regulator 21 and a second modulator 18.

The first resonator 3 is stimulated at resonant

15   frequency $\omega 1$. The resultant stimulating oscillation is tapped off, phase-demodulated by means of the first demodulator 7, and a demodulated signal component is supplied to the first low-pass filter 8 that removes the sum frequencies. (The tapped-off signal is also referred

20   to below as the stimulating oscillation tapped-off

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signal.) An output signal from the first low-pass filter
8 is applied to a frequency regulator 9 which controls the
VCO 10, as a function of the signal supplied to it, such
that the in-phase component essentially tends to zero.

5   The VCO 10 passes a signal to the first modulator 11,
which controls a force sensor such that a stimulating
force is applied to the first resonator 3. When the in-
phase component is zero, the first resonator 3 oscillates
at its resonant frequency $\omega 1$. (It should be noted that

10   all of the modulators and demodulators are operated on the
basis of resonant frequency $\omega 1$.)

The stimulating oscillation tapped-off signal is
also applied to the second control loop and demodulated by
the second demodulator 12. The output of the second

15   demodulator 12 is passed through the second low-pass
filter 13 whose output is, in turn, applied to the
amplitude regulator 14. The amplitude regulator 14
controls the first modulator 11 in response to this signal
and the output of a nominal amplitude sensor 23 to cause

20   the first resonator 3 to oscillate at a constant amplitude
(i.e. the stimulating oscillation has constant amplitude).

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As mentioned above, Coriolis forces (indicated by the term $FC \cdot \cos(\omega 1 \cdot t)$ in Figure 2) occur on movement/rotation of the Coriolis gyro 1. They couple the first resonator 3 to the second resonator 4, and thus

5   cause the second resonator 4 to oscillate. A resultant read oscillation of frequency $\omega 2$ is tapped off and a corresponding read oscillation tapped-off signal (read signal) is supplied to both the third and the fourth control loops. This signal is demodulated in the third

10   control loop by the third demodulator 15, sum frequencies are removed by the third low-pass filter 16, and the low-pass-filtered signal is supplied to the quadrature regulator 17. The output of the quadrature regulator 17 is applied to the third modulator 22 to reset

15   corresponding quadrature components of the read oscillation. Analogously, the read oscillation-tapped-off signal is demodulated in the fourth control loop by the fourth demodulator 19, passed through the fourth low-pass filter 20, and the low-pass-filtered signal then applied

20   to the rotation rate regulator 21 (whose output is proportional to the instantaneous rotation rate, and passed as a rotation rate measurement to a rotation rate output 24) and to the second modulator 18 that resets

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corresponding rotation rate components of the read oscillation.

A Coriolis gyro 1 as described above may be operated in both double-resonant and non-double-resonant forms. When operated in a double-resonant form, the frequency ω2 of the read oscillation is approximately equal to that of the stimulating oscillation (ω1). In the non-double-resonant case, the frequency ω2 of the read oscillation differs from ω1. In double resonance, the output signal from the fourth low-pass filter 20 contains corresponding information about the rotation rate. In contrast (non-double-resonant case), the output signal from the third low-pass filter 16 contains the rotation rate information. In order to switch between the double-resonant and non-double-resonant operating modes, a doubling switch 25 selectively connects the outputs of the third and the fourth low-pass filter 16, 20 to the rotation rate regulator 21 and the quadrature regulator 17.

The mass system 2 (resonator) generally has two or more natural resonances (i.e. different natural

oscillations of the mass system 2 can be stimulated). One
of the natural oscillations is artificially produced
stimulating oscillation. Another natural oscillation is
represented by the read oscillation, which is stimulated

5   by Coriolis forces upon rotation of the Coriolis gyro 1.
As a result of mechanical structure and unavoidable
manufacturing tolerances, it is impossible to prevent
other natural oscillations, in addition to the stimulating
oscillation and the read oscillation, of the mass system

10   2, in some cases far removed from resonance, from also
being stimulated. Such undesirably stimulated natural
oscillations change the read oscillation tapped-off signal
as they are also (at least partially) read with the read
oscillation signal tap. The read oscillation tapped-off

15   signal is thus composed of a part caused by Coriolis
forces and a part that originates from the stimulation of
undesired resonances. The undesirable part causes a zero
error of unknown magnitude. In such case it is not
possible to differentiate between the two parts when the

20   read oscillation signal is tapped off.

SUMMARY AND OBJECTS OF THE INVENTION

It is therefore an object of the invention to
provide a method for determining the influence of the
oscillations of "third" modes and thus, the zero error in
5   the tapped-off read oscillation of a Coriolis gyro.

The present invention addresses the above object
by providing, in a first aspect, a method for
determination of a zero error of a Coriolis gyro.
10   According to such method, the resonator of the Coriolis
gyro has appropriate disturbance forces applied to it such
that at least one natural oscillation of the resonator is
stimulated. Such natural oscillation differs from the
stimulating oscillation and from the read oscillation of
15   the resonator. A change in read signal that represents
the read oscillation and results from the stimulation of
at least one natural oscillation is determined as a
measure of the zero error.

In a second aspect, the invention provides a
20   Coriolis gyro characterized by a device for determination
of a zero error. Such device includes a disturbance unit.
The unit applies appropriate disturbance forces to the

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resonator of the Coriolis gyro so that at least one
natural oscillation of the resonator is stimulated that
differs from the stimulating oscillation and the read
oscillation of the resonator.

5   A disturbance signal detection unit is also
provided. Such unit determines a disturbance component as
a measure of the zero error. The disturbance component is
contained in a read signal that represents the read
oscillation produced by the stimulation of at least one
10   natural oscillation.

         The foregoing and other features of the
invention will become further apparent from the detailed
description that follows. Such description is accompanied
by a set of drawing figures in which numerals,
15   corresponding to those of the written description, point
to the features of the invention. Like numerals refer to
like features throughout both the written description and
the drawing figures.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic diagram of a Coriolis gyro in accordance with the present invention; and

Figure 2 is a schematic diagram of a Coriolis
5　gyro in accordance with the prior art.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Figure 1 is a schematic diagram of a Coriolis gyro in accordance with the present invention. In it, parts and devices which correspond to those of the prior
10　art device of Figure 2 are indicated by identical reference symbols and not discussed below. The method of the invention will be explained below with reference to Figure 1.

A reset Coriolis gyro includes a control and
15　evaluation unit 26, a modulator 27 (disturbance unit) having a variable frequency ωmod and, preferably an adjustable amplitude, demodulators 28, 29 that operate in quadrature at the frequency ωmod, and fifth and sixth low-pass filters 30 and 31. The disturbance unit 27
20　produces an alternating signal at the frequency ωmod. This is added to the force input of the stimulating

oscillation (first resonator 3). The signal is also

supplied as a reference signal to the demodulators 28, 29.

An alternating force, corresponding to the alternating

signal, is thus additionally applied to the resonator 2.

5 Such alternating force stimulates a further natural

oscillation (also referred to as a "third" natural mode)

of the resonator 2 (in addition to the stimulation

oscillation). The effects of the further natural

oscillation can be observed in the form of a disturbance

10 component in the read oscillation tapped-off signal.

The read oscillation tapped-off signal is

subjected to a demodulation process in phase and

quadrature with respect to the stimulation produced by the

modulator 27. Such demodulation process is performed by

15 the demodulators 28, 29 at the frequency ωmod

(disturbance frequency). The signal thus obtained is low-

pass filtered (by the fifth and the sixth low-pass filters

30, 31), and supplied to the control and evaluation unit

26.

20 The control and evaluation unit 26 controls the

frequency ωmod and, if appropriate, the stimulation

amplitude of the alternating signal produced by the

modulator 27, in such a way that the frequencies and

strengths of the "significant" third natural modes, as

well as their Q factors, are continuously determined.

5   Such factors are utilized by the control and evaluation

unit 26 to calculate respective instantaneous bias error.

Such calculated errors supplied to correct gyro bias.

     The idea on which the invention is based is to

artificially stimulate undesired natural oscillations of

10   the resonator (that is to say natural oscillations which

are neither the stimulating oscillation nor the read

oscillation) and to observe their effects on the read

oscillation tapped off signal. The undesired natural

oscillations are, in such case, stimulated by application

15   of appropriate disturbance forces to the resonator. The

"penetration strength" of such disturbances to the read

oscillation tapped-off signal represents a measure of the

zero error (bias) of the Coriolis gyro. Thus, if the

strength of a disturbance component contained in the read

20   oscillation tapped-off signal is determined and is

compared with the strength of the disturbance forces

producing this disturbance component, it is then possible

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to derive the zero error.

The artificial stimulation of the natural
oscillations and the determination of the "penetration" of
the natural oscillations to the read oscillation tapped-
off signal preferably takes place during operation of the
Coriolis gyro. However, the zero error can also be
established without the existence of any stimulating
oscillation.

Both the strength of the disturbance component
in the read signal and the resonance Q factor of the
corresponding natural oscillation must be determined in
order to determine the zero error. These values are then
calculated to obtain the zero error. To determine the
resonance Q factor, the frequency of the disturbance unit
must be detuned over the resonance while, at the same
time, carrying out a measurement by means of the
disturbance signal detector unit. This is preferably
achieved by means of software, whose function is as
follows:

- searching for the "significant" third

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(disturbing) natural resonances

- moving away from the associated resonance
curve

- calculating the Q factor and the strength

5   of the stimulation, and the "visibility" of

this third oscillation in the read channel;

and

- calculating the contribution of this third

oscillation to the bias on the basis of the

10   Q factor, strength and "visibility".

The bias can be compensated by calculation (e.g.
by means of software).

While this invention has been described with
reference to its presently-preferred embodiment, it is not

15   limited thereto. Rather, the invention is limited only
insofar as it is defined by the following set of patent
claims and includes within its cope all equivalents
thereof.